Computational Implementation for Seismic Assessment of Existing Structures

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Abstract. Increasing of seismic record in Brazil resulted in first Brazilian code of seismic NBR 15421:2006. Once publication succeed Brazilian sample building assessment must be developed in order to prevent or mitigate effects of horizontal accelerations from seismic. For preliminary screening of existent reinforced concrete structures qualitative Hirosawa method seems to be suitable to Brazilian reality. This paper aims to implement computationally seismic vulnerability assessment method in order to optimize assessments through opensource SMath Solver and programming language is C#. Adapted Hirosawa method compares resistance of building through seismic index of structure I_S and Seismic demand index I_{S0}. Index I_S is a product of indexes (Basic seismic index of structure, Irregularity index, Time index) and index I_{S0} is formed by zone index, ground index and usage index. Model structure proposed by literature are analyzed in different levels of seismic acceleration as well as types of soil defined by Brazilian seismic code in order to demonstrate usability of tool. Graphical interface and results obtained from the application are showed aiding in decision-taking about new refined assessments or feasible interventions.

Keywords: Seismic Vulnerability, Adapted Hirosawa Method, Seismic-V, Reinforced Concrete Structure

1   Introduction

1.1 Seismicity in Brazil

Seismicity in Brazil in general derives from reactivation of faults or even the creation of new ones due to strength of compression where south America is subjugated. Particularly earthquakes recorded have magnitude lower than 5 except some occurrences. It is known earthquake depends on hypocenter, ground type and structures under magnitude 5,0 may suffer potential damage or loss of lives. In Brazil in 2022 was recorded to 111 km in southwest of city of Taraucá (State of Acre) an earthquake with depth of focus 621,9 km and magnitude 6,5. Looking for reducing damage in structures and mainly to avoid total or partial collapse that hinders rescue and due to international requirements, it was published in 2006 first Brazilian code of seismic NBR 15.421: Design of Seismic Resistant Structures [2]. Seismicity regions are geographic area with similar seismic activity defined in Brazilian code vary from 0 to 4 regions being the last one high region seismicity noticed in northeast of Brazil. Nonetheless major geographic area of Brazil is seismicity region 0, earthquake up to 5 have been recorded in State of Mato Grosso and São Paulo as reminded by Parisenti [3]. Figure 1 illustrates map of seismic acceleration in horizontal direction proposed by code NBR 15.421.
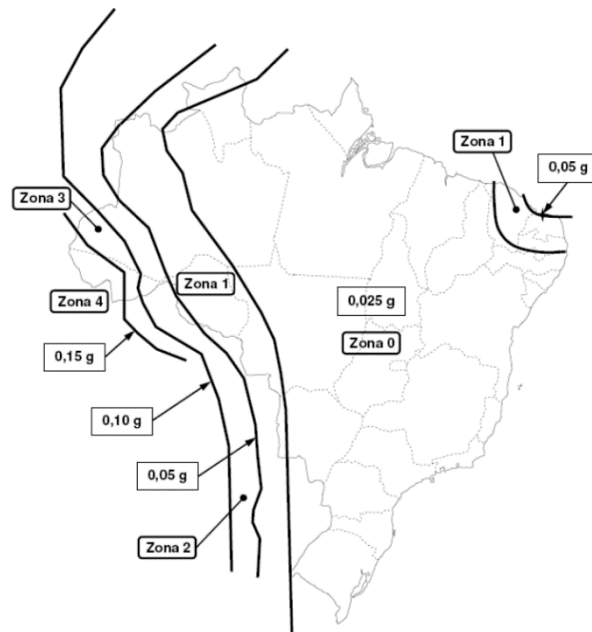
Figure 1. Map of seismic acceleration in horizontal direction in Brazil

About Brazilian Samples Building is crucial to known seismic vulnerability once designs were developed without considering seismic actions. In order to achieve, qualitative methods are suggested to a rapid visual screening of sample Building to identify level of safety. Hirosawa Method adjusted by Miranda [4] highlights due to rapid application and allows preliminary evaluation of buildings. This research seeks to implement computationally this method in opensource package *SMath Solver,* allowing to generate executable codes to verify seismic vulnerability of existing reinforced concrete structures. Program will be validated by applying in model structures defined in literature by Miranda [4].

2   Modified Hirosawa Method

Seismic Performance of reinforced concrete structures is evaluated comparing Seismic index of Structure I_S and Seismic demand index of structure I_{S0} It shall be calculated bat each story and in each principal horizontal direction of a building. The Index I_S is compared with I_{S0}. If $I_S \geq I_{S0}$ building possess safety against expected earthquake motions, otherwise if $I_S \leq I_{S0}$, building may possess uncertain performance against expected earthquake motion.

$$I_S \geq I_{S0} \tag{1}$$

Index I_S is shall be calculated considering basic seismic index of structure E_0, Irregularity index S_D, and time index T_D.

$$I_S = E_0 \cdot S_D \cdot T_D \tag{2}$$

Where:

E_0: Basic seismic index of structure

S_D: Irregularity index

T_D: Time index

Index E_0 evaluate the seismic performance of building taking in account number of story, story ultimate strength, story-shear and ductility of structures and model failure and if vertical member are column, extremely short column or wall.

Index S_D seeks to modify the basic index of structure and examines shape complexity, vertical irregularity, stiffness. Items to be considered are floor plan, plan regularity, narrow part, expansion joint, existence of basement, existing of pilotis and uniformity of story height.

Structural performance is impacted by time aging determined by time index T. This index evaluate deflection,

cracking in wall, columns according Budling inspection. Seismic demand index of structure I_{S0} shall be calculated by equation bellow:

$$I_{S0} = E_S \cdot Z \cdot G \cdot U \qquad (7)$$

Where E_S: 0,8 for first level screening, Z is Zone index related to seismic activities and seismic intensities expected in the region according to map from code ABNT NBR 15421 and the ground index G accounts the effects of amplification of the surface soil and geological conditions. The last one, usage index U names importance of building where U = 1,0 for general buildings.

Filho [5] proposes the use of surfaces to illustrate the behavior of Seismic index of Structure in function of Time index and Irregularity index. It is also applicable to seismic demand index of structure in function of zone index and use index of buildings.

3   Computational Code: Seismic-V 1.0 beta version

Seismic-V was developed in order to aid in preliminary phase of seismic vulnerability assessment and e a identify potentially hazardous buildings (Figure 2-a). In box *pavimento* requires number of story trough a slider varying from one floor up to eight floors according limited by the method (Figure 2-b). In second slider, is defined which floor is being evaluated. Next step program asks area of story, weight of the building upper the story under evaluation, sum of the cross-sectional area of the column and fundamental period of structure. After, it should be selected L, T or U-shaped plan.
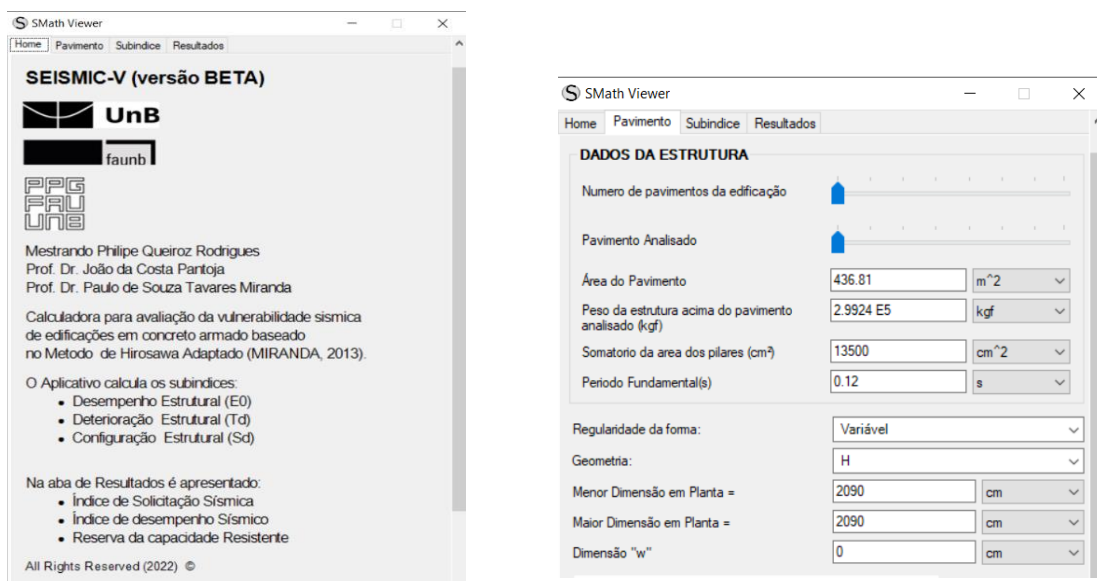

Figure 2. (a) Homepage of application, (b) Data of Floor

Third box, *Subíndice,* allows to calculate Basic seismic index of structure E_0 where program asks compressive strength of concrete, height of story, column depth pilar so that to obtain average shear stress at the ultimate state of column (Figure 3-a). Afterwards, program calculates E_0. Visual inspection should be carried out and interview with owner to take T minimum value to each item and relevance degree.   Irregularity index S_D is also calculated in this box.
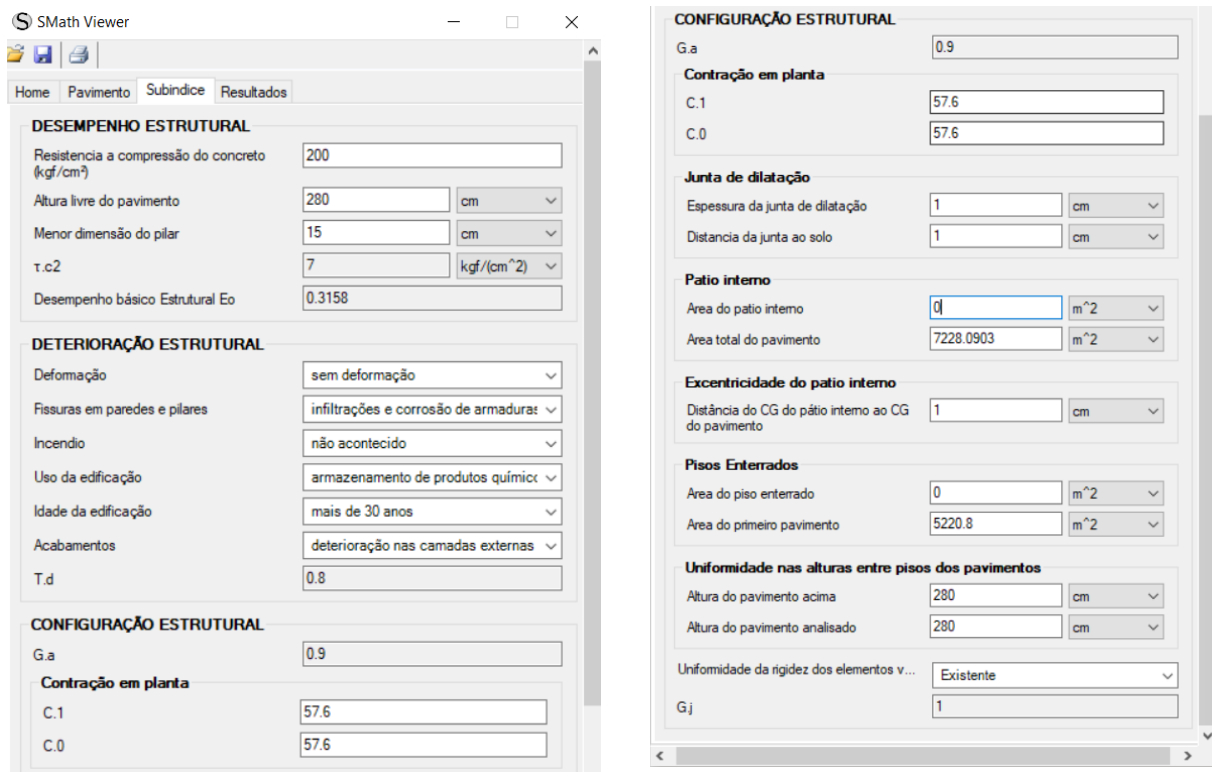
Figure 3. (a) Calculation of indexes E_0 and T_D (b) Calculation of indexes S_D

Last window application still receives data from user as region seismicity where structure belongs, geological soil conditions and factor of usage. Consecutively application brings together all indexes calculated before (E_0, S_D, T_D) and their product results in seismic index of structure (Figure 4-b). Seismic demand index of structure must be among minimum and maximum demand. When compared I_S and I_{S0} two answers may be displayed; "Estrutura Segura" which means structure is safety if $I_S \geq I_{S0}$ or "Verifique por outro método" which means Structure may have uncertain seismic performance against the assumed earthquake if k $I_S < I_{S0}$ and should be verified by next level of method. Reserve of resistant capacity is calculated by the relation seismic and demand index of structure and it is showed at the end of the window. All the indexes are exhibited to easy many simulations rapidly by just changing region seismicity, importance of building or even soil conditions.
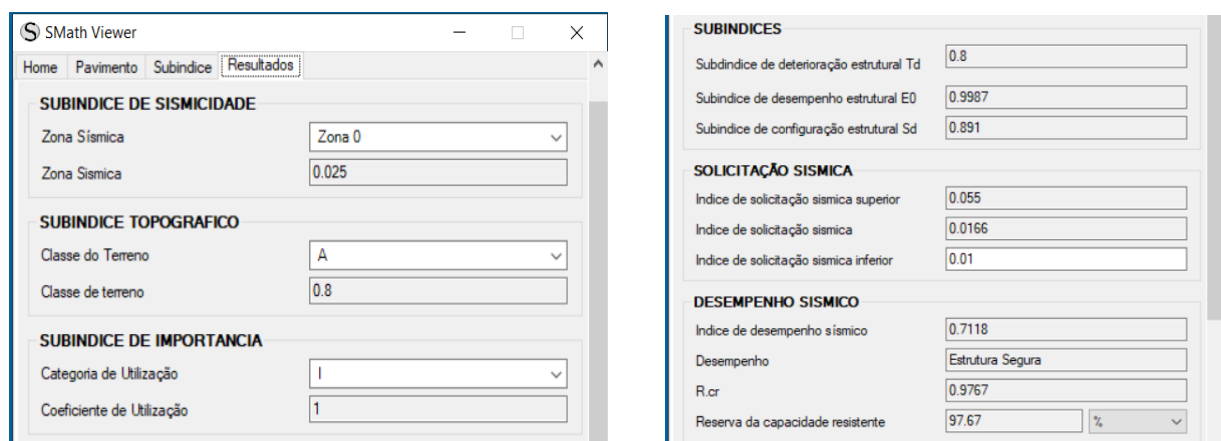

Figure 4. (a)Index of seismicity (b) Result of Seismic index of Structure and e Seismic demand index of structure

4 Application example

Model structures acquired from literature [4] were taken as application example of the program. The input values as sum of cross-sectional area of column, weight of the building upper the story under evaluation, fundamental period of structure and indexes of structure (E_0, S_D, T_D) are presented in table 1. Structure model I (Figure 5) has compressive strength of concrete 20 MPa. The height story is 2,80 and clear span is 4,00 m. Cross-sectional Columns is (15x25) cm² and beams with cross-sectional 15x40 cm² and slabs in reinforced concrete with thickness of 10 cm. This structure model owns only one story in square plan (20,90m x 20,90) with area of 436,81 m² (Figure 6). According to literature, time index is Td = 0,9 and use index is U = 1,5 (essential usage).
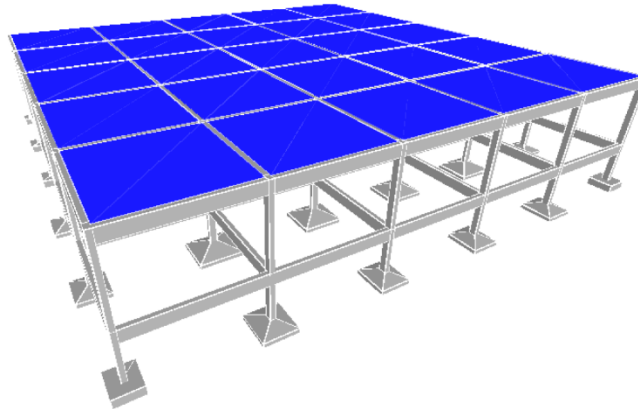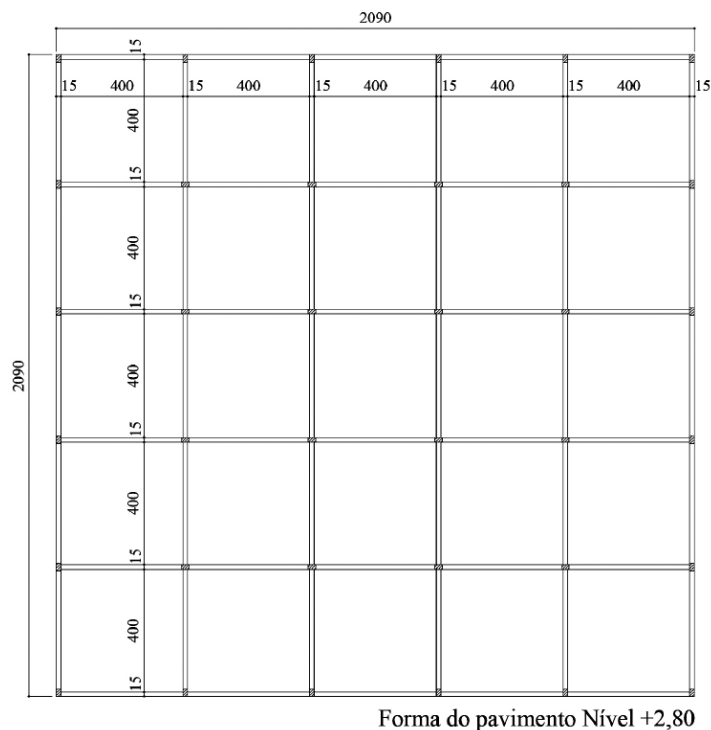

Figure 5. Model Structure

Forma do pavimento Nível +2,80

Figure 6. Plant of level floor +2,80 of Model Structure

Table 1. Input data of Model Structure I from reference [5]

	Floor 1	Floor 2
Level of floor	+2,80	-
Weight of the building upper the story (W) in kgf	299.236,00	-
Floor area in m²	436,81	-
Sum of cross-sectional area of column Ac2) in cm²	13.500,00	-
Fundamental Period (Ta) in seconds	0,12	-
Basic seismic index of structure E_0	0,32	-
Irregularity Index S_D	1,00	-
Time Index T_D	0,90	-
Seismic index of Structure I_S	0,28	-

Output after processing in software Seismic-V are compared with those calculated by hand calculation in reference [4] and seen in table 2. For structure model I, time index I was identically as adopted in the original example.

Table 2. Indexes calculated by software Seismic-V

	Seismic-V	Miranda (2013)
Index E_0	0,3158	0,32
Index S_D	0,99	1,00
Index T_D	0,9	0,9
Seismic index of Structure I_S	0,2814	0,28

Seismic demand indexes of structure were estimated by software Seismic-V and simulate structure in any scenarios as changing Zone index and considering any type of soil classified in code NBR 15421. Theses outputs are given in table 4 and compared with reference [4] (table 3).

Table 3 Seismic demand indexes I_{S0} of Model Structure I calculated by Miranda

Zone index	Ground index				
	A	B	C	D	E
	Miranda (2013)	Miranda (2013)	Miranda (2013)	Miranda (2013)	Miranda (2013)
0	0,03	0,03	0,04	0,05	0,08
1	0,05	0,06	0,08	0,10	0,16
2	0,10	0,13	0,15	0,20	0,31
3 e 4	0,15	0,19	0,23	0,28*	0,39

Table 4. Seismic demand indexes I_{S0} of Model Structure I obtained by program Seismic-V

Zone index	Ground index				
	A	B	C	D	E
	Seismic-V	Seismic-V	Seismic-V	Seismic-V	Seismic-V
0	0,0249	0,0311	0,0374	0,0498	0,0778
1	0,0498	0,0622	0,0747	0,0996	0,1556
2	0,0996	0,1245	0,1494	0,1992	0,3113

| 3 e 4 | 0,1494 | 0,1868 | 0,2241 | 0,2801* | 0,3922 |

Output obtained by Seismic-V are close to Miranda [4], as given before in table. As it occurred in original example, seismic index of Ground index 'E' was lower than inferior seismic demand. In this situation, application display a message: "*Verifique por outro método*", suggesting user to evaluate structure in more refined methods. In other scenarios, different message was displayed: "*Estrutura segura*", proving structure may have enough seismic performance against seismic expected.

Surface of seismic index for model structure (Figure 7) were generated considering Basic seismic index of structure $E_0 = 0,32$. Values of T_D and S_D vary from 0,7 to 1,0 and 0,8 to 1,0, respectively.
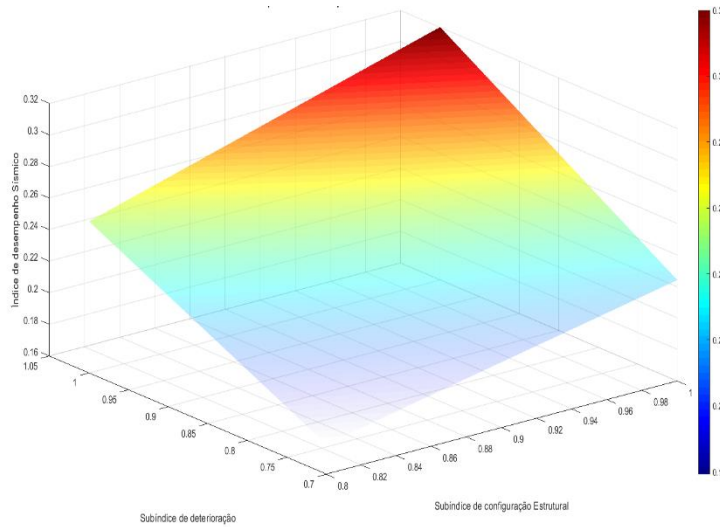

Figure 7 Surface of seismic index

Also surface of seismic demand indexes connecting use index of building change from 1,0 to 1,5 and zone index beginning from 0,025g to 0,15g (Figure 8)
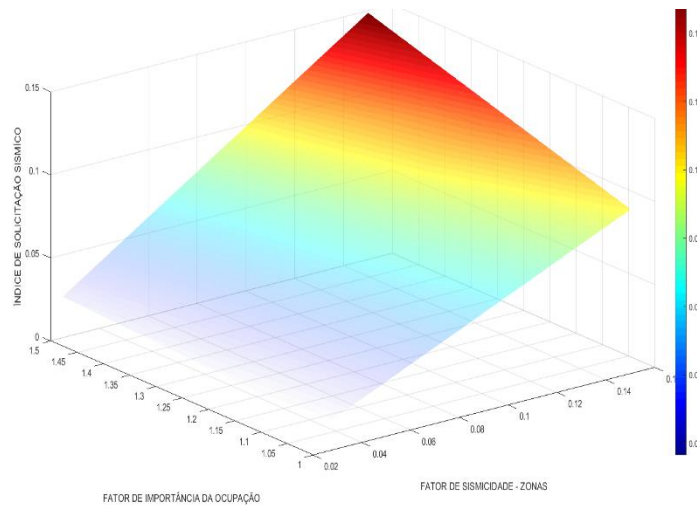

Figure 8. Surface of seismic demand

5   Conclusions

This word proposed a computational implementation of Modified Hirosawa Method to verify preliminary seismic vulnerability of reinforced concrete buildings. From comparison established with literature examples, program Seismic-V seems to be viable tool for first screening structures and may be applied in a large sample of buildings. For the same Building, the application allows to simulate its vulnerability in various scenarios whether be changing zone index, importance of building or soils conditions. Displaying values of each index easy the understanding of which variable impacts directly in seismic behavior of structures. As limitation the tool does not store inputs in a database to compare seismic performance of different typology of Building. As future implementation it will be generated surface of seismic indexes and seismic demand indexes according to proposed by Filho [7]. It is emphasized the routine is in beginning of development and integrates research about seismic vulnerability from Laboratory of Rehabilitation of Built Environment of University of Brasilia.

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